

Chapter 11 Inheritance and Polymorphism



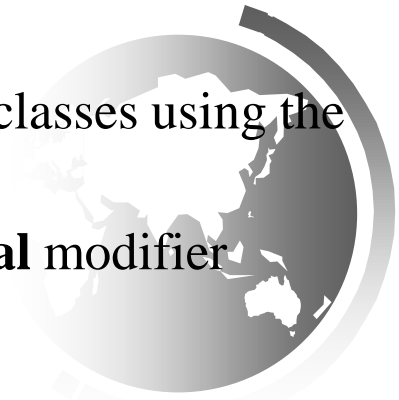
Motivations

Suppose you will define classes to model circles, rectangles, and triangles. These classes have many common features. What is the best way to design these classes so to avoid redundancy? The answer is to use inheritance.



Objectives

- To define a subclass from a superclass through inheritance (§11.2).
- To invoke the superclass's constructors and methods using the **super** keyword (§11.3).
- To override instance methods in the subclass (§11.4).
- To distinguish differences between overriding and overloading (§11.5).
- To explore the **toString()** method in the **Object** class (§11.6).
- To discover polymorphism and dynamic binding (§§11.7–11.8).
- To describe casting and explain why explicit downcasting is necessary (§11.9).
- To explore the **equals** method in the **Object** class (§11.10).
- To store, retrieve, and manipulate objects in an **ArrayList** (§11.11).
- To implement a **Stack** class using **ArrayList** (§11.12).
- To enable data and methods in a superclass accessible from subclasses using the **protected** visibility modifier (§11.13).
- To prevent class extending and method overriding using the **final** modifier (§11.14).



Superclasses and Subclasses

GeometricObject
-color: String -filled: boolean -dateCreated: java.util.Date
+GeometricObject() +GeometricObject(color: String, filled: boolean) +getColor(): String +setColor(color: String): void +isFilled(): boolean +setFilled(filled: boolean): void +getDateCreated(): java.util.Date +toString(): String

The color of the object (default: white).

Indicates whether the object is filled with a color (default: false).

The date when the object was created.

Creates a GeometricObject.

Creates a GeometricObject with the specified color and filled values.

Returns the color.

Sets a new color.

Returns the filled property.

Sets a new filled property.

Returns the dateCreated.

Returns a string representation of this object.

Circle
-radius: double
+Circle() +Circle(radius: double) +Circle(radius: double, color: String, filled: boolean) +getRadius(): double +setRadius(radius: double): void +getArea(): double +getPerimeter(): double +getDiameter(): double +printCircle(): void

Rectangle
-width: double -height: double
+Rectangle() +Rectangle(width: double, height: double) +Rectangle(width: double, height: double, color: String, filled: boolean) +getWidth(): double +setWidth(width: double): void +getHeight(): double +setHeight(height: double): void +getArea(): double +getPerimeter(): double

GeometricObject

CircleFromSimpleGeometricObject

RectangleFromSimpleGeometricObject

TestCircleRectangle

Run

Are superclass's Constructor Inherited?

No. They are not inherited.

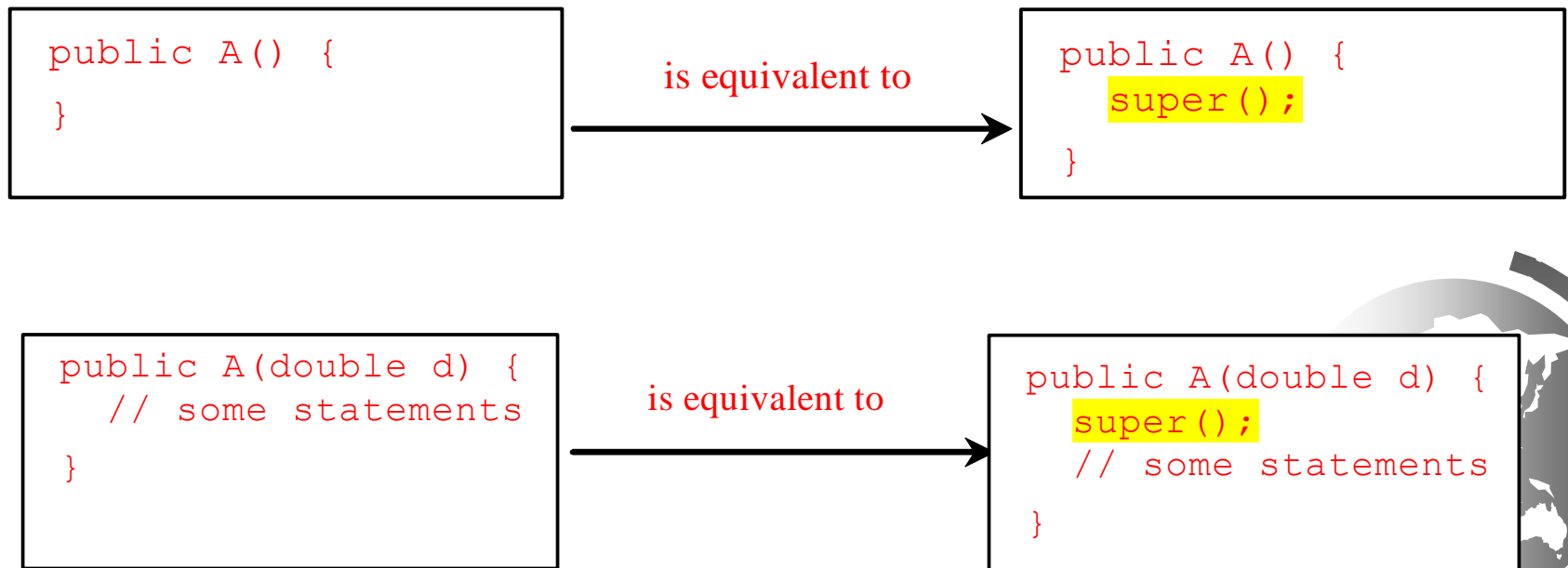
They are invoked explicitly or implicitly.

Explicitly using the `super` keyword.

A constructor is used to construct an instance of a class. Unlike properties and methods, a superclass's constructors are not inherited in the subclass. They can only be invoked from the subclasses' constructors, using the keyword `super`. *If the keyword `super` is not explicitly used, the superclass's no-arg constructor is automatically invoked.*

Superclass's Constructor Is Always Invoked

A constructor may invoke an overloaded constructor or its superclass's constructor. If none of them is invoked explicitly, the compiler puts super() as the first statement in the constructor. For example,



Using the Keyword `super`

The keyword `super` refers to the superclass of the class in which `super` appears. This keyword can be used in two ways:

- To call a superclass constructor

- To call a superclass method



CAUTION

You must use the keyword super to call the superclass constructor. Invoking a superclass constructor's name in a subclass causes a syntax error. Java requires that the statement that uses the keyword super appear first in the constructor.



Constructor Chaining

Constructing an instance of a class invokes all the superclasses' constructors along the inheritance chain. This is known as *constructor chaining*.

```
public class Faculty extends Employee {
    public static void main(String[] args) {
        new Faculty();
    }

    public Faculty() {
        System.out.println("(4) Faculty's no-arg constructor is invoked");
    }
}

class Employee extends Person {
    public Employee() {
        this("(2) Invoke Employee's overloaded constructor");
        System.out.println("(3) Employee's no-arg constructor is invoked");
    }

    public Employee(String s) {
        System.out.println(s);
    }
}

class Person {
    public Person() {
        System.out.println("(1) Person's no-arg constructor is invoked");
    }
}
```



Trace Execution

```
public class Faculty extends Employee {  
    public static void main(String[] args) {  
        new Faculty();  
    }  
  
    public Faculty() {  
        System.out.println("(4) Faculty's no-arg constructor is invoked");  
    }  
}  
  
class Employee extends Person {  
    public Employee() {  
        this("(2) Invoke Employee's overloaded constructor");  
        System.out.println("(3) Employee's no-arg constructor is invoked");  
    }  
  
    public Employee(String s) {  
        System.out.println(s);  
    }  
}  
  
class Person {  
    public Person() {  
        System.out.println("(1) Person's no-arg constructor is invoked");  
    }  
}
```

1. Start from the
main method



Trace Execution

```
public class Faculty extends Employee {  
    public static void main(String[] args) {  
        new Faculty();  
    }  
  
    public Faculty() {  
        System.out.println("(4) Faculty's no-arg constructor is invoked");  
    }  
}  
  
class Employee extends Person {  
    public Employee() {  
        this("(2) Invoke Employee's overloaded constructor");  
        System.out.println("(3) Employee's no-arg constructor is invoked");  
    }  
  
    public Employee(String s) {  
        System.out.println(s);  
    }  
}  
  
class Person {  
    public Person() {  
        System.out.println("(1) Person's no-arg constructor is invoked");  
    }  
}
```

2. Invoke Faculty
constructor



Trace Execution

```
public class Faculty extends Employee {  
    public static void main(String[] args) {  
        new Faculty();  
    }  
  
    public Faculty() {  
        System.out.println("(4) Faculty's no-arg constructor is invoked");  
    }  
}  
  
class Employee extends Person {  
    public Employee() {  
        this("(2) Invoke Employee's overloaded constructor");  
        System.out.println("(3) Employee's no-arg constructor is invoked");  
    }  
  
    public Employee(String s) {  
        System.out.println(s);  
    }  
}  
  
class Person {  
    public Person() {  
        System.out.println("(1) Person's no-arg constructor is invoked");  
    }  
}
```

3. Invoke Employee's no-arg constructor



Trace Execution

```
public class Faculty extends Employee {  
    public static void main(String[] args) {  
        new Faculty();  
    }  
  
    public Faculty() {  
        System.out.println("(4) Faculty's no-arg constructor is invoked");  
    }  
}  
  
class Employee extends Person {  
    public Employee() {  
        this("(2) Invoke Employee's overloaded constructor");  
        System.out.println("(3) Employee's no-arg constructor is invoked");  
    }  
  
    public Employee(String s) {  
        System.out.println(s);  
    }  
}  
  
class Person {  
    public Person() {  
        System.out.println("(1) Person's no-arg constructor is invoked");  
    }  
}
```

4. Invoke Employee(String)
constructor



Trace Execution

```
public class Faculty extends Employee {  
    public static void main(String[] args) {  
        new Faculty();  
    }  
  
    public Faculty() {  
        System.out.println("(4) Faculty's no-arg constructor is invoked");  
    }  
}  
  
class Employee extends Person {  
    public Employee() {  
        this("(2) Invoke Employee's overloaded constructor");  
        System.out.println("(3) Employee's no-arg constructor is invoked");  
    }  
  
    public Employee(String s) {  
        System.out.println(s);  
    }  
}  
  
class Person {  
    public Person() {  
        System.out.println("(1) Person's no-arg constructor is invoked");  
    }  
}
```

5. Invoke Person() constructor

Trace Execution

```
public class Faculty extends Employee {  
    public static void main(String[] args) {  
        new Faculty();  
    }  
  
    public Faculty() {  
        System.out.println("(4) Faculty's no-arg constructor is invoked");  
    }  
}  
  
class Employee extends Person {  
    public Employee() {  
        this("(2) Invoke Employee's overloaded constructor");  
        System.out.println("(3) Employee's no-arg constructor is invoked");  
    }  
  
    public Employee(String s) {  
        System.out.println(s);  
    }  
}  
  
class Person {  
    public Person() {  
        System.out.println("(1) Person's no-arg constructor is invoked");  
    }  
}
```

6. Execute println

Trace Execution

```
public class Faculty extends Employee {  
    public static void main(String[] args) {  
        new Faculty();  
    }  
  
    public Faculty() {  
        System.out.println("(4) Faculty's no-arg constructor is invoked");  
    }  
}  
  
class Employee extends Person {  
    public Employee() {  
        this("(2) Invoke Employee's overloaded constructor");  
        System.out.println("(3) Employee's no-arg constructor is invoked");  
    }  
  
    public Employee(String s) {  
        System.out.println(s);  
    }  
}  
  
class Person {  
    public Person() {  
        System.out.println("(1) Person's no-arg constructor is invoked");  
    }  
}
```

7. Execute println

Trace Execution

```
public class Faculty extends Employee {  
    public static void main(String[] args) {  
        new Faculty();  
    }  
  
    public Faculty() {  
        System.out.println("(4) Faculty's no-arg constructor is invoked");  
    }  
}  
  
class Employee extends Person {  
    public Employee() {  
        this("(2) Invoke Employee's overloaded constructor");  
        System.out.println("(3) Employee's no-arg constructor is invoked");  
    }  
  
    public Employee(String s) {  
        System.out.println(s);  
    }  
}  
  
class Person {  
    public Person() {  
        System.out.println("(1) Person's no-arg constructor is invoked");  
    }  
}
```



8. Execute println

Trace Execution

```
public class Faculty extends Employee {  
    public static void main(String[] args) {  
        new Faculty();  
    }  
}
```

```
public Faculty() {  
    System.out.println("(4) Faculty's no-arg constructor is invoked");  
}  
}
```

9. Execute println

```
class Employee extends Person {  
    public Employee() {  
        this("(2) Invoke Employee's overloaded constructor");  
        System.out.println("(3) Employee's no-arg constructor is invoked");  
    }  
}
```

```
public Employee(String s) {  
    System.out.println(s);  
}  
}
```

```
class Person {  
    public Person() {  
        System.out.println("(1) Person's no-arg constructor is invoked");  
    }  
}
```



Example on the Impact of a Superclass without no-arg Constructor

Find out the errors in the program:

```
public class Apple extends Fruit {  
}  
  
class Fruit {  
    public Fruit(String name) {  
        System.out.println("Fruit's constructor is invoked");  
    }  
}
```



Defining a Subclass

A subclass inherits from a superclass. You can also:

- Add new properties

- Add new methods

- Override the methods of the superclass



Calling Superclass Methods

You could rewrite the printCircle() method in the Circle class as follows:

```
public void printCircle() {  
    System.out.println("The circle is created " +  
        super.getDateCreated() + " and the radius is " + radius);  
}
```



Overriding Methods in the Superclass

A subclass inherits methods from a superclass. Sometimes it is necessary for the subclass to modify the implementation of a method defined in the superclass. This is referred to as *method overriding*.

```
public class Circle extends GeometricObject {  
    // Other methods are omitted  
  
    /** Override the toString method defined in GeometricObject */  
    public String toString() {  
        return super.toString() + "\nradius is " + radius;  
    }  
}
```



NOTE

An instance method can be overridden only if it is accessible. Thus a private method cannot be overridden, because it is not accessible outside its own class. If a method defined in a subclass is private in its superclass, the two methods are completely unrelated.



NOTE

Like an instance method, a static method can be inherited. However, a static method cannot be overridden. If a static method defined in the superclass is redefined in a subclass, the method defined in the superclass is hidden.



Overriding vs. Overloading

```
public class Test {  
    public static void main(String[] args) {  
        A a = new A();  
        a.p(10);  
        a.p(10.0);  
    }  
}  
  
class B {  
    public void p(double i) {  
        System.out.println(i * 2);  
    }  
}  
  
class A extends B {  
    // This method overrides the method in B  
    public void p(double i) {  
        System.out.println(i);  
    }  
}
```

```
public class Test {  
    public static void main(String[] args) {  
        A a = new A();  
        a.p(10);  
        a.p(10.0);  
    }  
}  
  
class B {  
    public void p(double i) {  
        System.out.println(i * 2);  
    }  
}  
  
class A extends B {  
    // This method overloads the method in B  
    public void p(int i) {  
        System.out.println(i);  
    }  
}
```

The Object Class and Its Methods

Every class in Java is descended from the `java.lang.Object` class. If no inheritance is specified when a class is defined, the superclass of the class is `Object`.

```
public class Circle {  
    ...  
}
```

Equivalent

```
public class Circle extends Object {  
    ...  
}
```

The toString() method in Object

The toString() method returns a string representation of the object. The default implementation returns a string consisting of a class name of which the object is an instance, the at sign (@), and a number representing this object.

```
Loan loan = new Loan();  
System.out.println(loan.toString());
```

The code displays something like **Loan@15037e5** . This message is not very helpful or informative. Usually you should override the toString method so that it returns a digestible string representation of the object.



Polymorphism

Polymorphism means that a variable of a supertype can refer to a subtype object.

A class defines a type. A type defined by a subclass is called a *subtype*, and a type defined by its superclass is called a *supertype*. Therefore, you can say that **Circle** is a subtype of **GeometricObject** and **GeometricObject** is a supertype for **Circle**.



PolymorphismDemo

Run

Polymorphism, Dynamic Binding and Generic Programming

```
public class PolymorphismDemo {
    public static void main(String[] args) {
        m(new GraduateStudent());
        m(new Student());
        m(new Person());
        m(new Object());
    }

    public static void m(Object x) {
        System.out.println(x.toString());
    }
}

class GraduateStudent extends Student {
}

class Student extends Person {
    public String toString() {
        return "Student";
    }
}

class Person extends Object {
    public String toString() {
        return "Person";
    }
}
```

Method `m` takes a parameter of the `Object` type. You can invoke it with any object.

An object of a subtype can be used wherever its supertype value is required. This feature is known as *polymorphism*.

When the method `m(Object x)` is executed, the argument `x`'s `toString` method is invoked. `x` may be an instance of `GraduateStudent`, `Student`, `Person`, or `Object`. Classes `GraduateStudent`, `Student`, `Person`, and `Object` have their own implementation of the `toString` method. Which implementation is used will be determined dynamically by the Java Virtual Machine at runtime. This capability is known as *dynamic binding*.

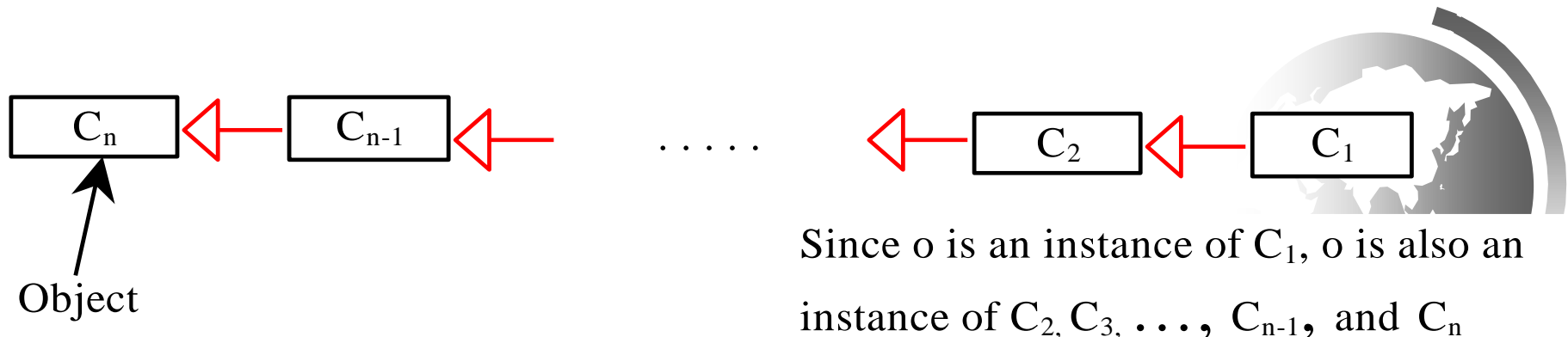
Animation

DynamicBindingDemo

Run

Dynamic Binding

Dynamic binding works as follows: Suppose an object o is an instance of classes C_1, C_2, \dots, C_{n-1} , and C_n , where C_1 is a subclass of C_2 , C_2 is a subclass of C_3 , ..., and C_{n-1} is a subclass of C_n . That is, C_n is the most general class, and C_1 is the most specific class. In Java, C_n is the Object class. If o invokes a method p , the JVM searches the implementation for the method p in C_1, C_2, \dots, C_{n-1} and C_n , in this order, until it is found. Once an implementation is found, the search stops and the first-found implementation is invoked.



Method Matching vs. Binding

Matching a method signature and binding a method implementation are two issues. The compiler finds a matching method according to parameter type, number of parameters, and order of the parameters at compilation time. A method may be implemented in several subclasses. The Java Virtual Machine dynamically binds the implementation of the method at runtime.



Generic Programming

```
public class PolymorphismDemo {
    public static void main(String[] args) {
        m(new GraduateStudent());
        m(new Student());
        m(new Person());
        m(new Object());
    }

    public static void m(Object x) {
        System.out.println(x.toString());
    }
}

class GraduateStudent extends Student {
}

class Student extends Person {
    public String toString() {
        return "Student";
    }
}

class Person extends Object {
    public String toString() {
        return "Person";
    }
}
```

Polymorphism allows methods to be used generically for a wide range of object arguments. This is known as generic programming. If a method's parameter type is a superclass (e.g., `Object`), you may pass an object to this method of any of the parameter's subclasses (e.g., `Student` or `String`). When an object (e.g., a `Student` object or a `String` object) is used in the method, the particular implementation of the method of the object that is invoked (e.g., `toString`) is determined dynamically.



Casting Objects

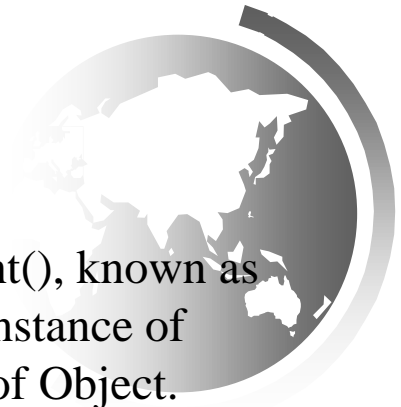
You have already used the casting operator to convert variables of one primitive type to another. *Casting* can also be used to convert an object of one class type to another within an inheritance hierarchy. In the preceding section, the statement

```
m(new Student());
```

assigns the object `new Student()` to a parameter of the `Object` type. This statement is equivalent to:

```
Object o = new Student(); // Implicit casting  
m(o);
```

The statement `Object o = new Student()`, known as implicit casting, is legal because an instance of `Student` is automatically an instance of `Object`.



Why Casting Is Necessary?

Suppose you want to assign the object reference `o` to a variable of the `Student` type using the following statement:

```
Student b = o;
```

A compile error would occur. Why does the statement **Object o = new Student()** work and the statement **Student b = o** doesn't? This is because a `Student` object is always an instance of `Object`, but an `Object` is not necessarily an instance of `Student`. Even though you can see that `o` is really a `Student` object, the compiler is not so clever to know it. To tell the compiler that `o` is a `Student` object, use an explicit casting. The syntax is similar to the one used for casting among primitive data types. Enclose the target object type in parentheses and place it before the object to be cast, as follows:

```
Student b = (Student)o; // Explicit casting
```

Casting from Superclass to Subclass

Explicit casting must be used when casting an object from a superclass to a subclass. This type of casting may not always succeed.

```
Apple x = (Apple) fruit;
```

```
Orange x = (Orange) fruit;
```



The instanceof Operator

Use the instanceof operator to test whether an object is an instance of a class:

```
Object myObject = new Circle();  
... // Some lines of code  
/** Perform casting if myObject is an instance of  
    Circle */  
if (myObject instanceof Circle) {  
    System.out.println("The circle diameter is " +  
        ((Circle)myObject).getDiameter());  
    ...  
}
```



TIP

To help understand casting, you may also consider the analogy of fruit, apple, and orange with the Fruit class as the superclass for Apple and Orange. An apple is a fruit, so you can always safely assign an instance of Apple to a variable for Fruit. However, a fruit is not necessarily an apple, so you have to use explicit casting to assign an instance of Fruit to a variable of Apple.



Example: Demonstrating Polymorphism and Casting

This example creates two geometric objects: a circle, and a rectangle, invokes the `displayGeometricObject` method to display the objects. The `displayGeometricObject` displays the area and diameter if the object is a circle, and displays area if the object is a rectangle.



CastingDemo

Run

The equals Method

The `equals()` method compares the contents of two objects. The default implementation of the `equals` method in the `Object` class is as follows:

```
public boolean equals(Object obj) {  
    return this == obj;  
}
```

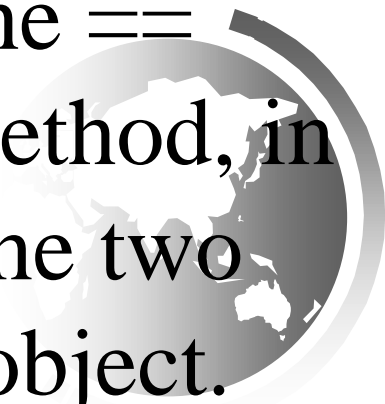
For example, the `equals` method is overridden in the `Circle` class.

```
public boolean equals(Object o) {  
    if (o instanceof Circle) {  
        return radius == ((Circle)o).radius;  
    }  
    else  
        return false;  
}
```



NOTE

The `==` comparison operator is used for comparing two primitive data type values or for determining whether two objects have the same references. The `equals` method is intended to test whether two objects have the same contents, provided that the method is modified in the defining class of the objects. The `==` operator is stronger than the `equals` method, in that the `==` operator checks whether the two reference variables refer to the same object.



The ArrayList Class

You can create an array to store objects. But the array's size is fixed once the array is created. Java provides the ArrayList class that can be used to store an unlimited number of objects.

java.util.ArrayList<E>

```
+ArrayList()  
+add(o: E) : void  
+add(index: int, o: E) : void  
+clear(): void  
+contains(o: Object): boolean  
+get(index: int) : E  
+indexOf(o: Object) : int  
+isEmpty(): boolean  
+lastIndexOf(o: Object) : int  
+remove(o: Object): boolean  
+size(): int  
+remove(index: int) : boolean  
+set(index: int, o: E) : E
```

Creates an empty list.

Appends a new element *o* at the end of this list.

Adds a new element *o* at the specified index in this list.

Removes all the elements from this list.

Returns true if this list contains the element *o*.

Returns the element from this list at the specified index.

Returns the index of the first matching element in this list.

Returns true if this list contains no elements.

Returns the index of the last matching element in this list.

Removes the element *o* from this list.

Returns the number of elements in this list.

Removes the element at the specified index.

Sets the element at the specified index.

Generic Type

ArrayList is known as a generic class with a generic type E. You can specify a concrete type to replace E when creating an ArrayList. For example, the following statement creates an ArrayList and assigns its reference to variable cities. This ArrayList object can be used to store strings.

```
ArrayList<String> cities = new ArrayList<String>();
```

```
ArrayList<String> cities = new ArrayList<>();
```



TestArrayList

Run

Differences and Similarities between Arrays and ArrayList

Operation	Array	ArrayList
Creating an array/ArrayList	<code>String[] a = new String[10]</code>	<code>ArrayList<String> list = new ArrayList<>();</code>
Accessing an element	<code>a[index]</code>	<code>list.get(index);</code>
Updating an element	<code>a[index] = "London";</code>	<code>list.set(index, "London");</code>
Returning size	<code>a.length</code>	<code>list.size();</code>
Adding a new element		<code>list.add("London");</code>
Inserting a new element		<code>list.add(index, "London");</code>
Removing an element		<code>list.remove(index);</code>
Removing an element		<code>list.remove(Object);</code>
Removing all elements		<code>list.clear();</code>



DistinctNumbers

Run

Array Lists from/to Arrays

Creating an ArrayList from an array of objects:

```
String[] array = {"red", "green", "blue"};
```

```
    ArrayList<String> list = new  
ArrayList<>(Arrays.asList(array));
```

Creating an array of objects from an ArrayList:

```
String[] array1 = new String[list.size()];  
list.toArray(array1);
```



max and min in an Array List

```
String[] array = {"red", "green", "blue"};
```

```
System.out.println(java.util.Collections.max(  
    new ArrayList<String>(Arrays.asList(array))));
```

```
String[] array = {"red", "green", "blue"};
```

```
System.out.println(java.util.Collections.min(  
    new ArrayList<String>(Arrays.asList(array))));
```



Shuffling an Array List

```
Integer[] array = {3, 5, 95, 4, 15, 34, 3, 6, 5};  
ArrayList<Integer> list = new  
    ArrayList<>(Arrays.asList(array));  
java.util.Collections.shuffle(list);  
System.out.println(list);
```



The MyStack Classes

A stack to hold objects.



MyStack	
-list: ArrayList	
+isEmpty(): boolean	
+getSize(): int	
+peek(): Object	
+pop(): Object	
+push(o: Object): void	
+search(o: Object): int	

A list to store elements.

Returns true if this stack is empty.

Returns the number of elements in this stack.

Returns the top element in this stack.

Returns and removes the top element in this stack.

Adds a new element to the top of this stack.

Returns the position of the first element in the stack from the top that matches the specified element.

The protected Modifier

The protected modifier can be applied on data and methods in a class. A protected data or a protected method in a public class can be accessed by any class in the same package or its subclasses, even if the subclasses are in a different package.

private, default, protected, public

Visibility increases
→
private, none (if no modifier is used), protected, public

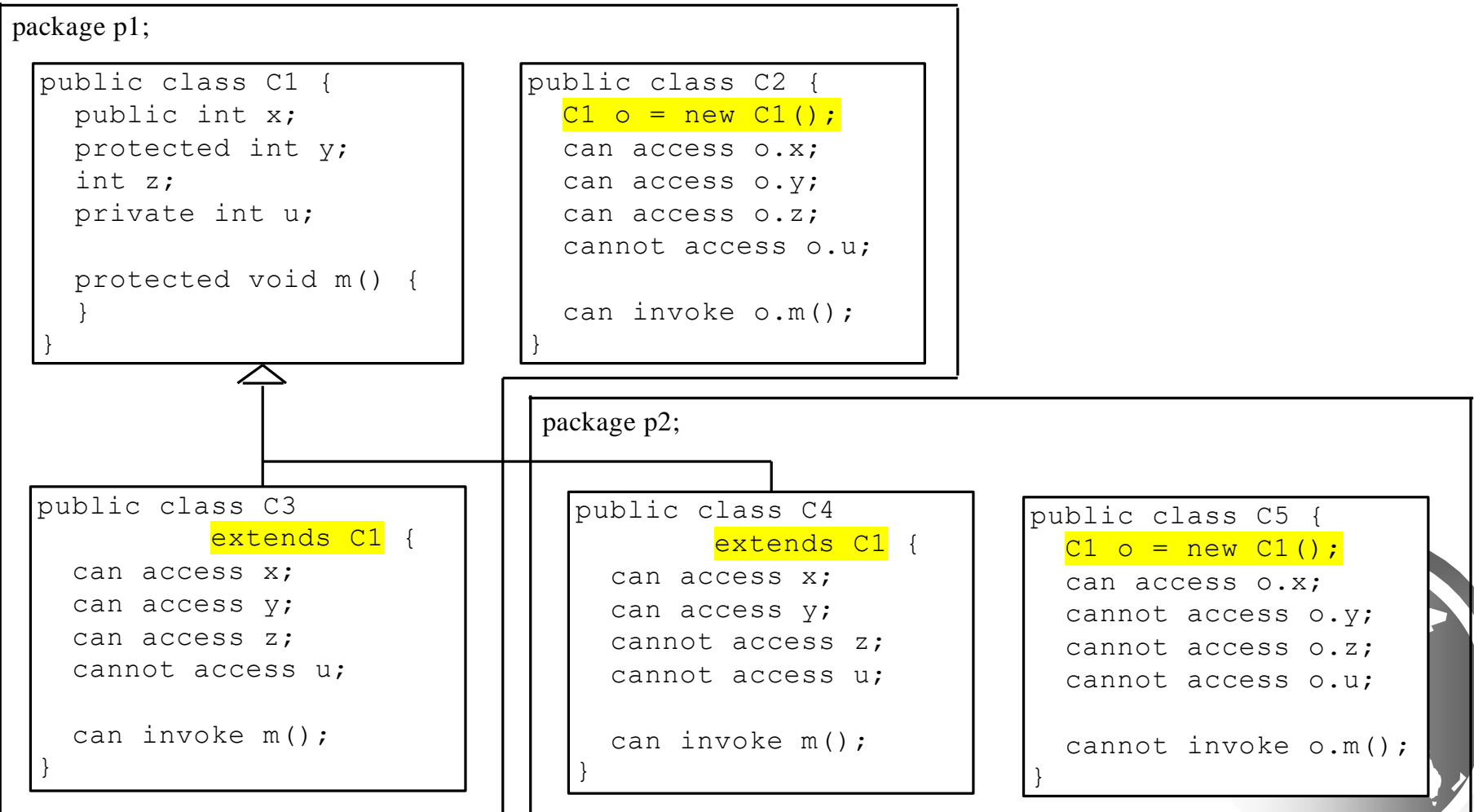


Accessibility Summary

Modifier on members in a class	Accessed from the same class	Accessed from the same package	Accessed from a subclass	Accessed from a different package
public	✓	✓	✓	✓
protected	✓	✓	✓	-
default	✓	✓	-	-
private	✓	-	-	-



Visibility Modifiers



A Subclass Cannot Weaken the Accessibility

A subclass may override a protected method in its superclass and change its visibility to public. However, a subclass cannot weaken the accessibility of a method defined in the superclass. For example, if a method is defined as public in the superclass, it must be defined as public in the subclass.



NOTE

The modifiers are used on classes and class members (data and methods), except that the final modifier can also be used on local variables in a method. A final local variable is a constant inside a method.



The `final` Modifier

The `final` class cannot be extended:

```
final class Math {  
    ...  
}
```

The `final` variable is a constant:

```
final static double PI = 3.14159;
```

The `final` method cannot be overridden by its subclasses.

